This gives $\mathrm{H} = 0{\cdot}1952. \quad t = 286.$

$$\mathrm{H}/t = 6{\cdot}83 \times 10^{-4}.$$

This the last, and, I believe, the best, result, is almost exactly equal to ϑ for the solution.

With the last apparatus and a solution of nitrate of copper, for which ϑ was measured and found $= 6{\cdot}14$, a perfect balance in both directions was obtained

with

$$\begin{aligned} \mathrm{C} &= 245 \quad \text{potentiometer} \\ \mathrm{R} &= 1{\cdot}05 \quad\quad ,, \\ \mathrm{S} &= 11{\cdot}695 \quad\quad ,, \\ \mathrm{H} &= 0{\cdot}1764. \quad t = 288. \end{aligned}$$

$$\mathrm{H}/t = 6{\cdot}1 \times 10^{-4}.$$

I should have liked to do a few more solutions, but something went wrong with the insulation of the bobbins, and I had no time to repair them. However, these two results appear to be enough to enable us to say that the equation

$$d\mathrm{E}/dt = \mathrm{H}/t$$

is true for the junctions of the kind under examination, and that these thermo-electric phenomena are reversible.

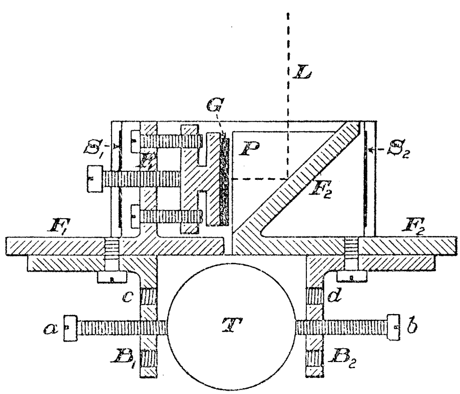
VII. "Experimental Determination of Poisson's Ratio." By C. E. Stromeyer. Communicated by Lord Kelvin, P.R.S. Received April 12, 1894.

The experiments with which this paper deals were carried out between the years 1883 and 1886 by Professor Kennedy and the author, with an instrument which the latter had originally designed for measuring local strains in metal structures, but which proved itself to be so exceedingly sensitive that it seemed capable of being applied to the measuring of the cross contraction of test pieces while these were subjected to a longitudinal pull, thus providing the means for measuring Poisson's ratio direct. In its original form the instrument consisted of two small frames, which were secured to each other by means of two flat springs, in such a manner, that any relative motion was a perfectly parallel one. One of these frames carried a small piece of dark glass, and close to it, but on the other frame, a right-angled reflecting glass prism was secured. The two glass surfaces, which faced each other, were then carefully adjusted, so as to

be nearly parallel, and, on throwing yellow sodium light into the prism, interference bands could be seen in the reflected light, and these would move either in one direction or the other, according as to whether the two glass surfaces, and with them their two frames, were either moving towards or away from each other. By counting the number of interference bands, which passed a mark which had been scratched on the dark glass, it was possible to estimate the amount of the relative motion of the two glass surfaces, each band representing a motion of half a wave-length of sodium light, or about 0·0000116 in. A centre point projected from the under-side of each frame, and these could be pressed against that part of the structure where it was intended to measure the variations of strains.

Subsequently these centre points were replaced by two small brackets and set screws, and in this form the instrument has been

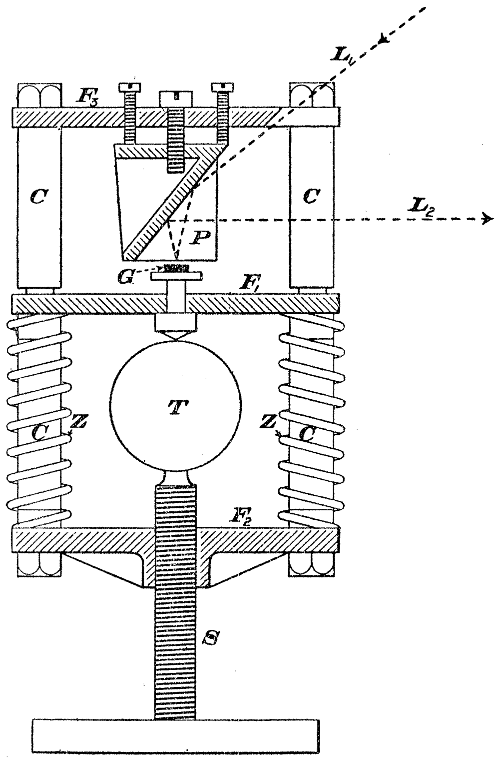
FIG. 1.—Instrument A.



used in the following experiments. Fig. 1 shows a section through the instrument as altered, F_1 and F_2 are the two frames, S_1, S_2 are the flat springs holding them together and keeping them parallel, G is the black glass, P is the right-angled reflecting prism, and L the ray of sodium light. B_1 and B_2 are the two brackets, and T is the section of the test piece in position and ready for testing.

It was soon found that the results which were obtained with this instrument differed materially from those which were obtained by less direct methods; it was therefore taken to South Kensington and calibrated in a Whitworth measuring machine in company with Mr. Boys, by carefully comparing the relative motion of the two screws *a* and *b*, fig. 1, with the number of interference bands which had passed the mark on the dark glass. It was found that each band represented 0·0000144 in. Evidently the spring of the brackets and

FIG. 2.—Instrument B.



of the frames must account for this large difference, namely, 24 per cent., over the true value of 0·0000116 in. Although the cause might be known, this large correction introduced an element of uncertainty, which the author hoped to eliminate by constructing a new instrument, B, fig. 2.

In this sketch, T is the section of the test piece, which is pressed against the point on the frame F_1 by the screw S. G is the dark glass, which, as soon as T contracts, is pulled away from the glass prism P by means of the four helical springs Z, Z, which surround the columns C, C, and which are firmly secured to the frames F_2, F_3. The latter carry the adjustable glass prism P, which is so shaped that the ray of yellow sodium light L_1 does not fall together with its reflected ray L_2. The inclination of the rays of light in the narrow space between the prism P and the dark glass G was carefully measured, and found to be 19°, so that each interference band, as seen in the reflected yellow light, ought to represent a distance of 0·0000109 in., but careful measurements with the fine screw S showed

it to represent 0·0000120 in., or 10 per cent. more. Both instruments A and B were used, and in the Table each experiment is marked with a distinguishing letter. In the earliest experiments (marked A_1) a spirit lamp was used for illuminating purposes; it was enclosed in an asbestos-lined casing, but this soon got very hot, and must have affected the readings. Later on a Bunsen burner was used, and the test piece and instrument screened from its radiant heat. These experiments are marked A_2, but even now the heat made itself felt, and the value $1/\mu$, last column, might in most of the experiments, as well as those marked B_2, be reduced 5 per cent. In the case of those marked B_3, the test piece was placed in position and the lamp lit from 30 to 60 minutes before commencing the readings.

In most of the early experiments (compare Columns 3 and 4) five, ten, and even twenty bands were counted between each reading of the steelyard of the testing machine. This was not only very fatiguing to the eye, but it was subsequently impossible to determine whether any interference bands had been wrongly counted. In the later experiments, two, or at the utmost three, bands were counted for each steelyard reading. Judging by the results, the central position of each band can be estimated to within 10 per cent., and in many experiments the total number counted exceeded 20. Each test piece was strained to the maximum intended load before each experiment; but, in spite of this, the first experiments were always slightly unsatisfactory, and have generally been rejected.

The author's original intention had been to use the instrument A both for measuring the longitudinal extension and the cross contraction, but as this instrument did not give reliable results as regards extensions, other strain indicators had to be used.

I. Professor Kennedy's Lever Gear (C_1). The short end of a little lever ended in a point, which was inserted into the centre punch mark at one end of a test piece. The fulcrum was connected to an arm, which was fixed to the other end of the test piece, and the long arm of the lever acted as a pointer. The leverage was 100 to 1. This instrument measured the elongation only on one side of the test piece, and would not give reliable results. In many of the experiments (those marked C_2) the instrument was first fixed on one side of the test piece and then on the other. The same remarks apply to the following gear, D_1 and D_2.

II. Mr. Stromeyer's Rolling-pin Gear D_1. Two flat plates with projecting centre points at either end were attached to the test piece. The rolling pin, which was placed between the two plates, and held there by helical springs, was a fine piece of hardened steel wire, to which a large straw pointer was attached. In the first experiments the leverage was about 300 to 1; in the later ones it was nearly 1,000 to 1.

Table.—Results of Experiments on Poissou's Ratio.

Reference No.	Material, sample number, diameter.	Number and nature of experiment.	Number of observations.	Instruments used.	Maximum stress of any experiment.	Mean stress for which values have been estimated.	E.	C.	σ.	Numbers of experiment selected.	Poisson's ratio $\frac{1}{\mu}=\frac{E}{C}$ or $\frac{E}{2\sigma}-1$.
					lbs.	lbs.	lbs.	lbs.	lbs.		
1	B.B. iron (Northamp-	2, tensile	22	C_1	22,000	..	27,670,000	..	..		
2	tonshire).	3 ,,	33	C_1	,,	..	30,000,000	..	..		
3	No. 75.	2 ,,	22	C_2	,,	..	27,450,000	..	..		
4	Diam. 0·749″.	3 ,,	18	A_2	24,000	..	..	102,200,000	..		
5		6 ,,	32	A_2	,,	..	..	102,700,000	..	1—5	0·279
6	B.B. iron (Staffordshire).	4, tensile	44	C_2	25,000	..	27,100,000	..	..		
7	No. 5041. Diam. 1·054″.	5 ,,	26	A_2	26,000	..	..	90,000,000	..	6, 7	0·301
8	Bessemer steel (Cam-	2, tensile	34	C_1	40,000	..	30,675,000	..	..		
9	mel's).	6 ,,	28	A_2	41,000	..	..	115,500,000	..		
10	No. 32. Diam. 0·748″.	4 ,,	26	A_2	40,000	..	..	104,300,000	..	8—10	0·279
11	Siemens-Martin steel	2, tensile	28	C_1	40,000	..	29,700,000	..	..		
12	(Landore).	3 ,,	18	B_2	30,000	10,500	..	108,600,000	..	11, 12	0·273
13	No. 9050. Diam. 0·855″.					23,000	..	99,200,000	..	11, 13	0·300
14	Cast (tool) steel. No. 5290. Diam. 1·008″.	3, torsion	18	F	17,900	..	..	..	13,430,000	8, 11, 14	0·187

Table—*continued.*

Reference No.	Material, sample number, diameter.	Number and nature of experiment.	Number of observations.	Instruments used.	Maximum stress of any experiment.	Mean stress for which values have been estimated.	E.	C.	σ.	Numbers of experiment selected.	Poisson's ratio $\frac{1}{\mu} = \frac{E}{C}$ or $\frac{E}{2\sigma} - 1$.
					lbs.	lbs.	lbs.	lbs.	lbs.		
15	Chilled cast iron.	4, tensile	110	D_2	6,200	..	21,250,000				
16	Diam. 1″.	6, torsion	97	F	11,000	..	..	..	6,700,000	15, 16	0·585
17						3,560	10,890,000	..	..	17, 22	0·179
18	Cast iron (turned).	7, tensile	98	C_2	12,000	6,630	10,080,000	..	..	18, 22	0·165
19	No. 820.					9,690	9,460,000	..	..	19, 22	0·155
20	Diam. 1·001″.					11,700	9,010,000	..	..	20, 22	0·148
21		4 ,,	20	A_2	13,000	..	..	72,000,000			
22		15 ,,	45	A_2	11,000	..	..	60,900,000			
23						3,500	17,180,000	..	..	23, 27	0·269
24	Cast iron (turned).	2, tensile	24	D_2	13,000	6,500	15,430,000	..	..	24, 27	0·243
25	No. 5086. 1.					9,500	13,730,000	..	..	25, 27	0·217
26	Diam. 1·074″.					12,000	14,130,000	..	..	26, 27	0·222
27		4 ,,	24	A_2	10,700	..	..	63,800,000			
28	Cast iron (black).					2,000	17,200,000	..	..	28, 31	0·225
29	No. 5086. 2.	3, tensile	9	D_2	13,000	7,000	14,600,000	..	..	29, 31	0·216
30	Diam. 1·028″.					13,000	12,800,000	..	..	30, 31	0·190
31		5 ,,	30	A_2	11,000	..	..	67,400,000			

Table—*continued.*

Reference No.	Material, sample number, diameter.	Number and nature of experiment.	Number of observations.	Instruments used.	Maximum stress of any experiment.	Mean stress for which values have been estimated.	E.	C.	σ.	Numbers of experiment selected.	Poisson's ratio $\frac{1}{\mu} = \frac{E}{C}$ or $\frac{E}{2\sigma} - 1$.
					lbs.	lbs.	lbs.	lbs.	lbs.		
32		4, tensile	40	C_1	20,000	..	16,700,000		..		
33		9 ,,	36	A_2	18,000	..	..	52,900,000	..		
34	Copper (best selected,	3 ,,	18	A_2	15,000	..	..	49,850,000	..		
35	rolled bar).	5 ,,	42	B_2	13,000	..	..	56,100,000	..		
36	No. 5070.	8 ,,	48	B_2	,,	..	..	54,400,000	..		
37	Diam. 0·998″.	4 ,,	40	B_3	19,000	..	..	51,500,000	..	32, 37	0·325
38		4, compression	68	B_3	20,000	..	..	52,400,000	..	32, 38	0·319
39		2, torsion	30	F	12,900	..	..	..	7,300,000	32, 39	0·168
40	Cast copper.	1, tensile	18	E	11,000	..	17,670,000	..	..		
41	No. 9702.	1, compression	24	E	,,	..	18,300,000	..	..		
42	Diam. 0·875″.	4, tension	36	B_3	18,000	..	..	49,300,000	..	40—42	0·366
43	Cast copper.	1, tensile	32	E	11,000	..	18,520,000	..	..		
44	No. 9703.	1, compression	24	E	,,	..	19,050,000	..	..		
45	Diam. 0·875″.	4, tensile	36	B_2	19,000	..	..	49,400,000	..	43—45	0·380
46	Bronze. No. 5208.	4, tensile	28	C_1 D_1	12,000	..	11,560,000	..	..		
47	Diam. 1·124″.	4, ,,	32	A_2	..	..	..	35,800,000	..	46, 47	0·323
48	Bronze. No. 5212.	2, tensile.	22	C_1	20,000	..	11,330,000	..	..		
49	Diam. 1·124″.	4, ,,	32	A_2	..	..	..	37,000,000	..	48, 49	0·305

Table—*continued*.

Reference No.	Material, sample number, diameter.	Number and nature of experiment.	Number of observations.	Instruments used.	Maximum stress of any experiment.	Mean stress for which values have been estimated.	E.	C.	σ.	Numbers of experiment selected.	Poisson's ratio $\frac{1}{\mu} = \frac{E}{C}$ or $\frac{E}{2\sigma} - 1$.
					lbs.	lbs.	lbs.	lbs.	lbs.		
50	Manganese bronze.	2, tensile	20	C_1	20,000	..	13,700,000	..			
51	(Forged.)	4, ,,	16	A_2	,,	..	..	40,200,000	..	50, 51	0·341
	No. 4995. Diam. 1·000″.										
52		2, tensile	26	C_1	30,000	..	13,800,000				
53	Manganese bronze.					7,500	..	42,400,000	..	52, 53	0·326
54	(Cold rolled.)	5, ,,	20	A_2	27,000	15,000	..	39,000,000	..	52, 54	0·354
55						23,000	..	38,100,000	..	52, 55	0·363
56		5, tensile	28	A_2	13,000	..	..	36,900,000	..		
57	Delta metal.	3, ,,	22	B_2	,,	..	..	31,700,000	..		
58	No. 5357.	4, ,,	40	B_3	14,000	..	..	34,200,000	..	58, 60	0·563
59	Diam. 1·007″.	3, compression	25	B_3	12,000	..	..	35,800,000	..	59, 60	0·525
60		5, torsion	27	F	9,000	..	..	..	6,160,000		
61						2,500	16,530,000	..	..	61, 66	0·357
62	Muntz metal.					5,500	14,930,000	..	..	62, 66	0·323
63	(Unannealed.)	4, tensile	60	C_2	12,000	8,000	14,050,000	..	..	63, 66	0·304
64	No. 5084.					10,000	13,700,000	..	..	64, 66	0·296
65	Diam. 0·975″.					11,500	13,080,000	..	..	65, 66	0·283
66		4, ,,	16	A_2	12,000	..	..	46,300,000			

Table—*continued.*

Reference No.	Material, sample number, diameter.	Number and nature of experiment.	Number of observations.	Instruments used.	Maximum stress of any experiment.	Mean stress for which values have been estimated.	E.	C.	σ.	Numbers of experiment selected.	Poisson's ratio $\frac{1}{\mu} = \frac{E}{C}$ or $\frac{E}{2\sigma} - 1$.
					lbs.	lbs.	lbs.	lbs.	lbs.		
67	Muntz metal.	3, tensile	36	C_2	12,000	..	14,100,000				
68	(Annealed.)				13,000	3,560	..	38,900,000	..	67, 68	0·363
69	No. 5085.	4, ,,	16	A_2		6,700	..	40,200,000	..	67, 69	0·351
70	Diam. 0·999″					10,000	..	43,000,000	..	67, 70	0·328

NOTE.—E is Young's modulus, *i.e.*, stress divided by the elongation of a unit of length.
C is the value of the fraction; stress divided by the cross contractions of a unit of the diameter.
σ is the value of the fraction; shearing stress divided by shearing angle.

No. 14. No tensile test was made in this case, and the mean value of Nos. 8 and 11 has been taken.

No. 15. This sample was so hard that it could not be machined, and the diameter could not be accurately ascertained.

Nos. 37—39. In order to make these three values agree, E should be 20,370,000.

Professor Kennedy's Needle Gear (E). Two frames were attached to either end of the test piece, and each one carried a long arm in such a position that the two were close alongside each other, but not touching. The index pointer was attached to a small brass frame from which two strong needle points, about one-tenth of an inch apart, projected; these rested in fine cross grooves which were cut on both arms, and any relative motion was magnified about a hundredfold. This instrument gives the average reading for two sides of a test piece.

One of the objects of these researches was, to ascertain whether Poisson's ratio, as determined by these experiments, agreed with the values as found by a comparison of tension and torsion tests, and in order to obtain reliable angular measurements of the twist, the author constructed an instrument (F), which consisted of two mirrors, which were attached to either end of a torsion test piece, in such a position that the doubly-reflected image of a scale, which was placed about 60 ft. away, coincided with the image as seen direct. A slight twist of the test piece produces a displacement of the two scales, and this is the measure of the torsion angle. The instrument is very sensitive and reliable for small angles.

Only a few of the samples were tested for torsion, but Messrs. Platt and Hargraves (Minutes of the Inst. of Civil Engineers, vol. xc, p. 387) have made experiments on 11 samples with the instruments C_1 and F, but as there is internal evidence that the results cannot be relied upon in all cases they have not been reproduced here.

Before discussing the results it will be necessary to consider how far the experiments are reliable. The instruments have already been discussed, but the methods also play an important part.

1st Method. Tensile test, measurement of elongation e and cross contraction c. The value of $1/\mu$ is c/e, and an error of 1 per cent. in either determination will affect $1/\mu$ by an equal amount.

2nd Method. Tensile test and measurement of elongation, and torsion test and measurement of shearing angle, α. In this case $1/\mu = \alpha\, 2e - 1$, and when this value is about 0·2, an error either in e or α produces a sixfold greater one in $1/\mu$. A 5 per cent. error in e, which is not unlikely, if it is only determined for one side, would absolutely spoil the conclusions. In most cases, $1/\mu$ found in this way is smaller than by the 1st Method, but, as will be seen (Table, Nos. 16 and 58), it sometimes is even greater than 0·500.

The conclusions to be drawn from the experiments with these nineteen samples are:—

1. That Poisson's ratio is not a constant value for all materials.

2. That mechanical treatment: cold rolling (No. 52) and annealing (No. 67) of the metal alter it.

3. That Poisson's ratio is sometimes a function of the stress (Nos. 12, 17, 23, 28, 53, 61, and 68).

4. That Poisson's ratio, as found by direct measurement, is not the same as that found by comparing torsion and tension experiments.

The work entailed in the digestion of these experiments, and their reduction to a small table, has been heavier than the author had anticipated, but as the results show that they are fairly reliable, they may be of use to those engaged in researches on elasticity. In conclusion, the author begs to thank Professor Kennedy, not only for allowing him the use of his testing machine, but also for directing each experiment, and personally taking its reading.

[April 30.—Somewhat similar experiments were carried out by Professor J. Bauschinger (see 'Der Civilingenieur,' 1879, 1881, 1882, &c.)].

Presents, April 19, 1894.

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FIG. 1.—Instrument A.

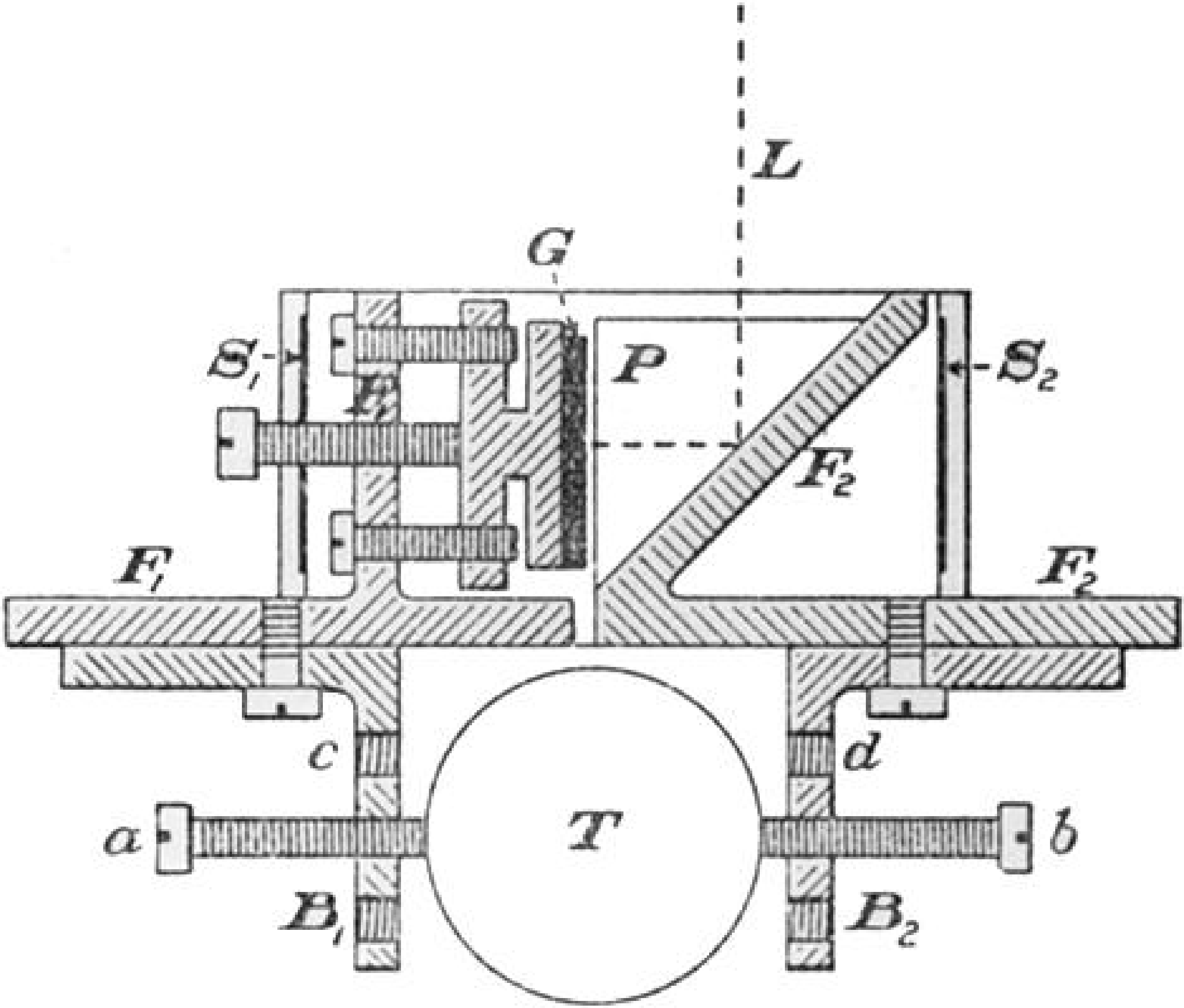

FIG. 2.—Instrument B.